

Star-planet interactions and selection effects from planet detection methods

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Received 2011 Sep 20, accepted 2011 Oct 6

Published online 2011

Key words planetary systems – stars: activity – X-rays: stars

Planets may have effects on their host stars by tidal or magnetic interaction. Such star-planet interactions are thought to enhance the activity level of the host star. However, stellar activity also affects the sensitivity of planet detection methods. Samples of planet-hosting stars which are investigated for such star-planet interactions are therefore subject to strong selection effects which need to be taken into account.

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1 Introduction

Magnetic activity is a well-known phenomenon in the Sun, and it is ubiquitous among late-type stars. The magnetic field of cool stars is highly structured at a local scale and is mainly responsible for the stellar chromospheric and coronal emission. Close binary stars display a much higher activity level than single stars of a comparable age and spectral type. This is mainly due to the fast stellar rotation in binaries which is preserved by tidal locking, but there is also evidence for direct magnetic interaction and coronal emission between the two components of close binaries (Siarkowski et al. 1996). Regarding a star and its giant close-in planet as a binary system with a very small mass ratio, such interactions might also be expected in star-planet systems.

The theoretical framework of star-planet interactions (SPI) discerns between tidal and magnetic interaction, which are both thought to be able to increase the stellar activity level (Cuntz et al. 2000). Tidal bulges caused by the planet in the stellar atmosphere rise and subside with respect to the stellar rotational frame if the planetary orbit and stellar rotation are not yet synchronized. This may increase the turbulence in the stellar photosphere and lead to faster entanglement of footpoints of coronal loops and therefore more frequent flaring. Magnetic interactions of the planet on the star may arise from reconnection events between stellar and planetary magnetic field lines (Ip et al. 2004), the propagation of Alfvén waves in the stellar wind (Preusse et al. 2006), or from disturbing effects that the planetary magnetosphere may have on stellar coronal loops such as flare triggering (Pillitteri et al. 2010).

2 SPI signatures in stellar coronae and chromospheres

Observing activity signatures caused by SPI is a difficult task since all cool stars display some level of intrinsic variability, causing both short-term and long-term activity changes. However, in some individual star-planet systems, indications for such signatures have been found. Out of ten program stars with Hot Jupiters (Shkolnik et al. 2005), the two stars HD 179949 and ν And showed variations in the activity-influenced chromospheric Ca II K line emission which were in phase with the planetary orbit, not the stellar rotation period. However, subsequent observations showed that the chromospheric variability had switched back to the stellar rotation period again (Poppenhaeger et al. 2011; Shkolnik et al. 2008). Recently, a possible influence of a Hot Jupiter on the photospheric spot distribution of its host star, CoRoT-6, was reported (Lanza et al. 2011). For the star HD 189733, which hosts a transiting Hot Jupiter, an X-ray flare has been detected which occurred directly after the eclipse (not the transit) of the planet; the authors interpret this as active region flares triggered by the planet (Pillitteri et al. 2010).

Several analyses of samples of planet-hosting stars have been conducted as well. In an initial statistical study which tested for trends of the stellar X-ray luminosity with planetary semimajor axis, Kashyap et al. (2008) reported elevated X-ray activity in stars with close-in planets. However, this trend could not be recovered in a later study using a complete sample of planet-hosting stars in the solar neighborhood (Poppenhaeger et al. 2010). A study of the chromospheric activity of planet-hosting stars did not detect a dependence of stellar activity on semimajor axis or planetary mass (Canto Martins et al. 2011).

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3 The influence of selection effects from planet-detection methods

Samples of planet-hosting stars can be a powerful tool to identify SPI-related trends in coronal activity. However, strong biases can arise from planet-detection methods. It is well known that stellar activity can mask radial velocity (RV) signals induced by planets, so that detecting small planets around active stars is notoriously difficult. In the light of observational programs which search for rocky planets in habitable zones, M dwarfs as host stars have gained lots of attention recently. Detailed studies of spot coverages and their influence on the RV detectability of rocky planets have been conducted (Barnes et al. 2011; Dumusque et al. 2011). In transit surveys, stellar activity has an influence on the derived planetary parameters, as star spots which are covered by the planet during the transit distort the transit profile and can lead to smaller estimates for the planetary radius if not accounted for (Czesla et al. 2009).

Other biases concerning the stellar activity level can arise from flux-limited surveys in X-rays. For example the X-ray detections of planet-hosting stars from the ROSAT All-Sky Survey (RASS), which is strongly flux limited, show a very prominent trend in stars with close-in (<0.15 AU) planets of stellar X-ray luminosity with the planetary mass (Scharf 2010), depicted by green data points in Fig. 1. However, the RASS is only complete with regard to stellar X-ray detections out to 5–10 pc, depending on the spectral type, so there is a distance-related selection effect in this set of data.

Therefore, we composed a sample of all known planet-hosting stars within a distance of 30 pc from the Sun (Poppenhaeger & Schmitt 2011). Combining new and archival X-ray observations conducted with XMM-Newton and ROSAT for this, our sample is practically complete with regard to X-ray detections (52 of 72 stars detected). The main difference to the RASS sample is that there are many stars with low L_X which harbour massive planets, filling up the lower right corner of the diagram in Fig. 1 (shaded in green). The previous lack in such systems obviously stems from the X-ray flux limit of the RASS data. This means that there is no dependence of some minimal L_X on the planetary mass.

However, there are no stars with high L_X and small planets in the sample (upper left corner, shaded in blue). Again, this is not an SPI signature, but an effect of the non-completeness with regard to planet detections: In the solar neighborhood, planets are mostly detected by radial velocity (RV) shifts. Stellar activity makes the detection of RV shifts more difficult, so that for active stars only strong RV signals can be detected, requiring a heavy planet, low-mass host star, or both. This means that small planets are only detected around low-activity stars by the RV method.

Transit detections are less influenced by stellar activity, and several small transiting planets have been discovered or-

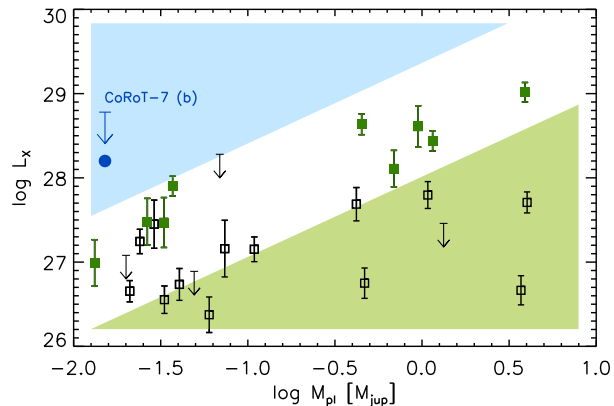


Fig. 1 (online colour at: www.an-journal.org) X-ray luminosities of stars with close-in planets ($a_{\text{pl}} < 0.15$ AU); flux-limited subsample as green filled squares, volume-limited complete sample in green and black, estimated L_X of CoRoT-7 (which hosts a transit-detected super-earth) as blue filled circle.

biting quite active stars. As a prominent example we discuss here the case of CoRoT-7b. CoRoT-7b was first detected as a companion causing a 0.034 % flux reduction of its host star during transit (Léger et al. 2009). The exact mass determination with the radial velocity method proved to be difficult, as the host star displays considerable magnetic activity, and the expected RV signal was of the order of only a few m/s. Detailed analyses have pinned down the planetary mass now to $6.9 M_{\oplus}$, classifying CoRoT-7b as a super-earth (Hatzes et al. 2010).

The host star CoRoT-7 is a main-sequence star of spectral type K0. Its X-ray flux has not been detected in the ROSAT All-Sky Survey (RASS); this non-detection yields an upper limit to CoRoT-7's X-ray luminosity of $\log L_X < 28.78$, assuming a distance of ≈ 150 pc (Léger et al. 2009). The chromospheric activity level inferred from the chromospheric Ca II H and K lines is given by Queloz et al. (2009) to be $\log R'_{HK} = -4.61$. Using the relation of chromospheric activity $\log R'_{HK}$ and coronal activity indicator $\log L_X/L_{\text{bol}}$ (Mamajek & Hillenbrand 2008), we estimate CoRoT-7's coronal activity indicator to be ≈ -5.1 . With bolometric corrections from Flower (1996), we derive a bolometric luminosity of $\log L_{\text{bol}} = 33.3$ and an estimated X-ray luminosity of $\log L_X = 28.2$. This is compatible with the upper limit derived from the RASS non-detection. The expected X-ray luminosity for CoRoT-7 is about one order of magnitude higher than for other (RV-detected) planet host stars with very small planets, as is evident from Fig. 1.

This prominent example shows that the absence of detected low-mass planets around active stars is a selection effect. This effect is very pronounced in near-by planet-hosting stars, because the radial velocity technique is the main planet detection method in the solar neighborhood. Transit-search missions such as Kepler and CoRoT are able

to detect small planets around more active stars, but they mostly detect planets around distant ($d > 100$ pc) stars. In principle, activity studies of stars with transit-detected planets can provide a new angle to the question of planet-induced activity features. However, the large distance to the host stars makes the characterization of their activity level via optical spectroscopy or X-ray flux detections time-expensive. A thorough treatment of selection effects in RV-detected samples is therefore inevitable.

4 Conclusion

We have investigated trends in the X-ray emission of planet-hosting stars within a distance of 30 pc from the Sun. We found that the apparent trend of X-ray luminosity with planetary mass can be explained by observational biases. Our analysis shows that selection effects which are introduced by the planet detection methods are crucial in the analysis of SPI signatures as they can produce spurious trends. In comparison, samples with transit-detected planets may yield more insight, since the transit method is better suited to find small planets around active stars than the radial velocity method.

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